



# Objectives

- Have a better understanding of the Tropical Cyclone Products generated at ECMWF
- Learn the recent developments in the forecast system and its impact on the Tropical Cyclone forecast
- Learn about the skill of TC forecasts in recent years


# Why is so important to forecast Tropical Cyclones?

- Tropical cyclone can cause massive loss of life in highly dense populated areas; STY Hayan in Philippines (2013); TC Nargis in Myanmar (2008), ...
  - **Fact:** Storm surge is the main cause of human fatalities
- They can cause major disruptions on economic activities
  - Off shore oil rigs
  - Ship routing



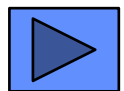
# Why TC forecasts have improved in recent years?

Due to the continuous upgrades of the forecast system at ECMWF,

- Increase of model horizontal and vertical resolution 
- Massive use of Satellite data in Data Assimilation (DA)
- Improvements of the physical processes (parametrization of convection, new cloud microphysics,... )
- Methods for Global Ensemble Prediction : ENS evolved SVs , stochastic physics and perturbations target at observed TCs and **more recently** the implementation of Ensemble Data Assimilation
- From last November:
  - *The atmosphere-ocean coupling of the ENS is active from initial time of the forecast using a new version of the NEMO ocean model (cy40r1)*

..... At ECMWF there is no artificial bogus vortex scheme for TCs. We allow the observations to do their job .....

Click me to jump to the next slide

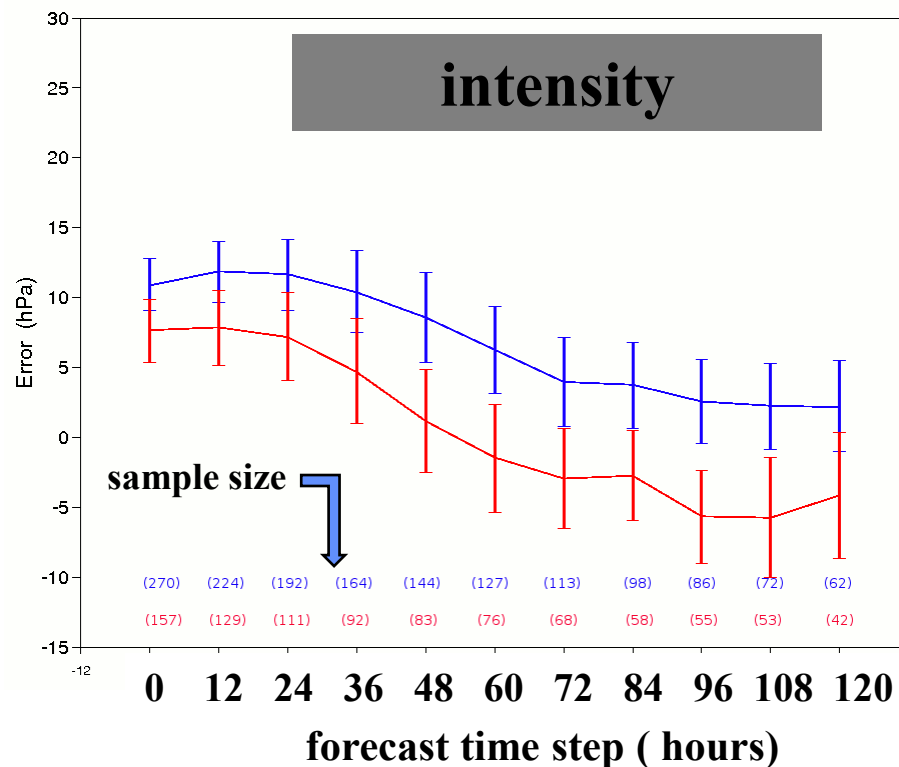
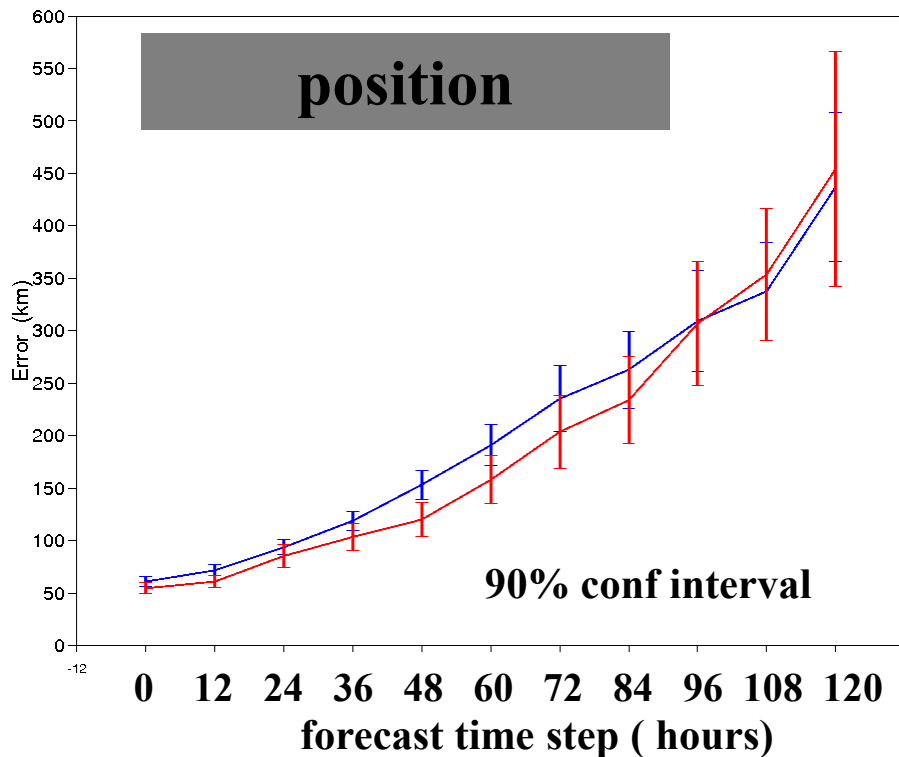


# TC forecast performance **T799** v **T1279**

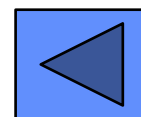
(~25 km)                      (~16 km)

Tropical cyclone mean position error  
fc period [20091004 to 20100121]

Tropical cyclone mean intensity error  
fc period [20091004 to 20100121]



*Error = Forecast – Obs*  
*Obs from the best track reports*



# Model resolution impact – Super Typhoon Haiyan

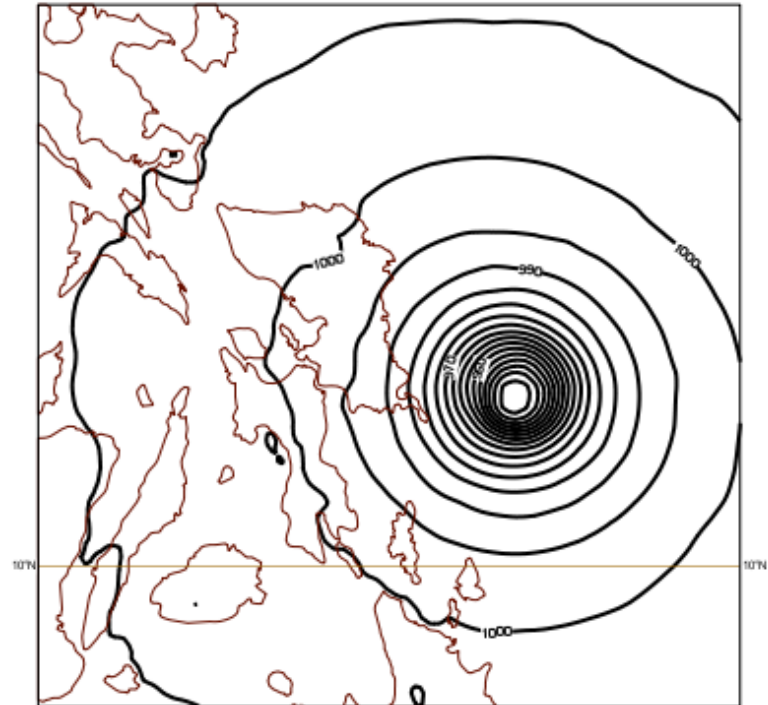
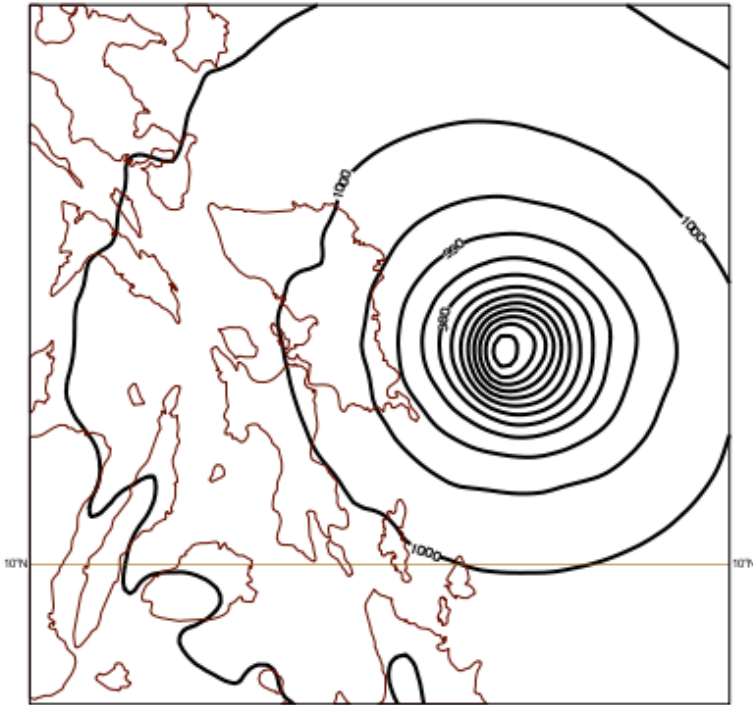
T1279 – min 943 hPa

T+48h

T2047 – min 922 hPa

2013-11-06 00:00:00 0z +48, Min pres: 943 (Obs: 895 hPa)

2013-11-06 00:00:00 0z +48, Min pres: 922 (Obs: 895 hPa)



5° ≈ 500 km

Courtesy of Linus Magnusson

# Why is important to have an operational tracking scheme running at the Centre?

- In operational environments, when the forecaster has to look at different NWP model outputs, the analysis of TC forecast is possible only when the information (position/intensity) is delivered (displayed) in a compact format (post-processing)
- It makes possible to verify objectively the TC forecasts. Can be used for comparing different model versions (model upgrades)
- **At ECMWF:**
  - Operational since 2003. The switch from the current to the new tracker was successfully implemented on **2<sup>nd</sup> December 2013**.
  - The algorithm runs twice a day (00 & 12 UTC) for high HRES model and ENS (51 perturbed members & control)
  - generates a track which is nothing more, nothing less than a sequence of locations of minimum (maximum) in MSLP (10m speed) every 6 hours.
  - **NEW:** TC tracks are produced up to 240h (previously 120h) & extra web products.

# What model fields are used in the tracking scheme?

## ➤ Surface fields

- Mean sea level pressure
- Wind at 10 m

## ➤ Upper level fields

- Vorticity (850 hPa)
- Wind (multi-levels) for steering wind
- Temperature (multi-levels) for warm core detection

The tracker is applied to NWP output every 6 hours and allows a tropical cyclone to 'disappear' for 24 hours (a tropical cyclone may weaken for a short period of time when crossing an island for instance).

**For more details see ECMWF Newsletter No 130:**

<http://www.ecmwf.int/publications/newsletters/>

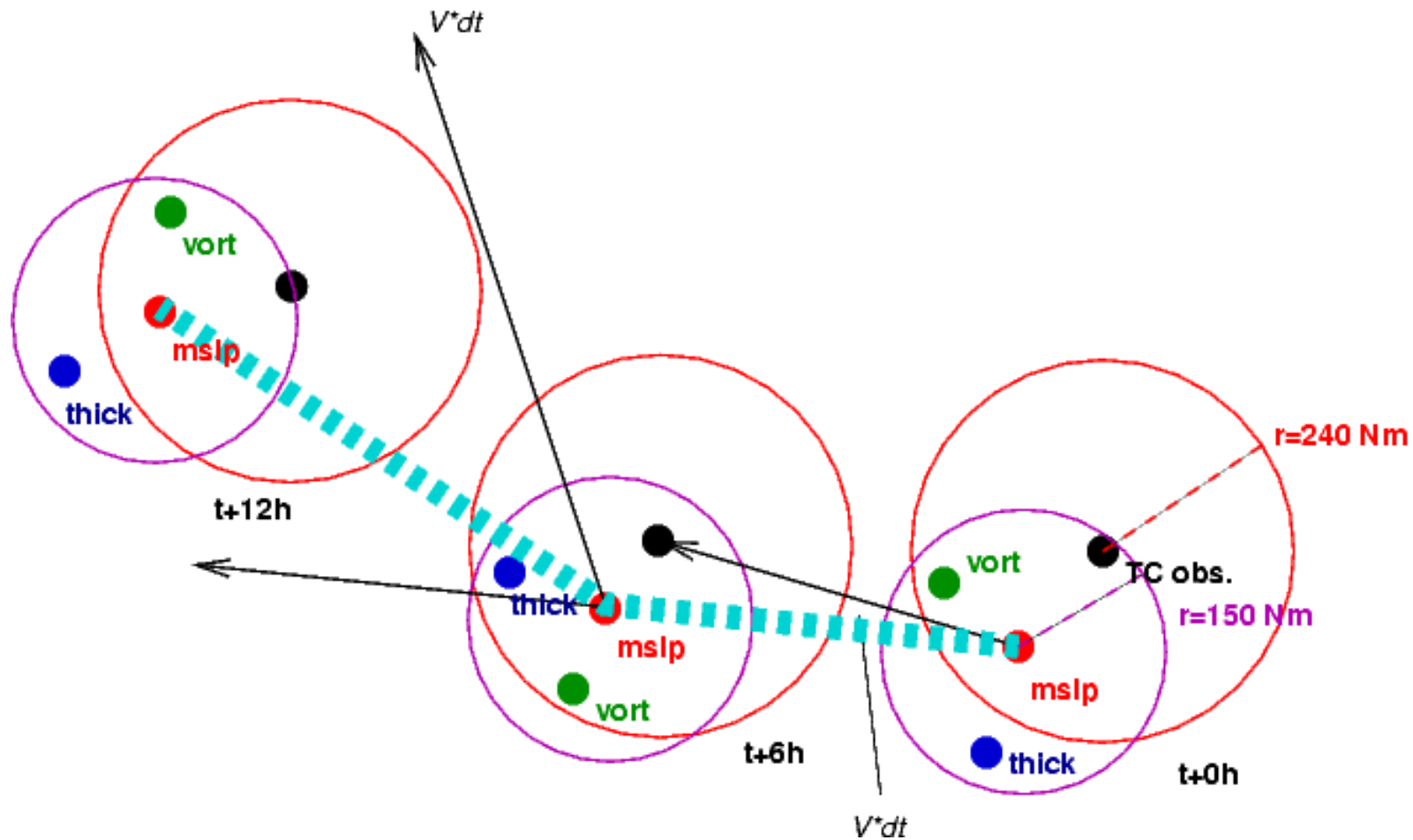


# ECMWF TC Tracker – How it works

vort 850hPa

V 850,700,500,200 hPa

warm core 500-200 hPa



# Tracker output (ALSO available in BUFR format)

Lat	Lon	ENS member (1, ...,51)	fc date	hour	mslp
36.94	-38.96	1	20121001	0	988
36.13	-39.4	1	20121001	600	997.6
35.4	-38.89	1	20121002	1200	999.7
35.09	-38.54	1	20121002	1800	999.6
34.52	-37.83	1	20121003	0	1005.6
33.99	-36.13	1	20121003	0600	1006.1
34.75	-33.02	1	20121004	1200	1003.6
37.2	-29.58	1	20121004	1800	995
36.8	-38.7	2	20121001	0	989

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36.93	-38.96	52	20121001	0	987.9
36.52	-39.09	52	20121001	600	986.9
36.02	-39.12	52	20121001	1200	992.6
35.61	-38.91	52	20121001	1800	993.6
35.37	-38.45	52	20121002	0	994.6

HRES model

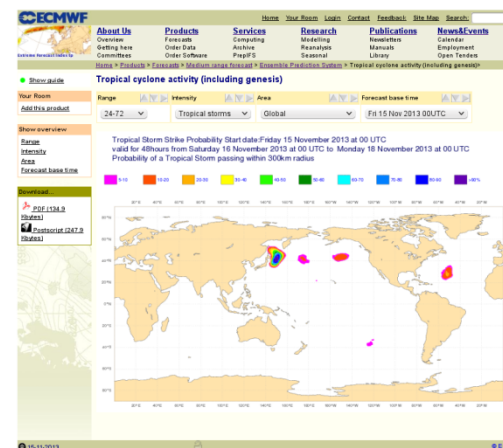
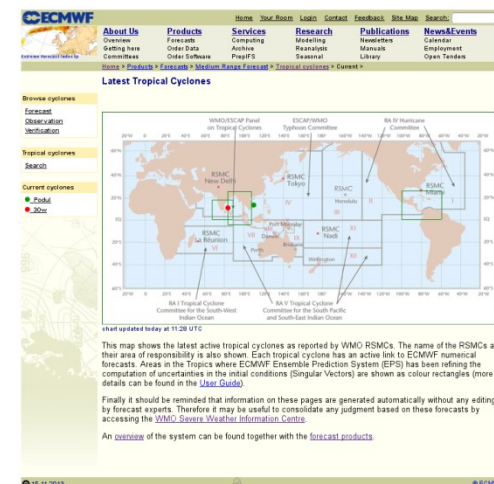
# Where can I find the web products?

- Whenever a Tropical Cyclone is observed at the start of a forecast

<http://www.ecmwf.int/products/forecasts/d/tccurrent>

- Whenever there is Tropical Cyclone activity in the forecast

[http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/genesis/ta\\_genesis/](http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/genesis/ta_genesis/)



# TC Products – Part I

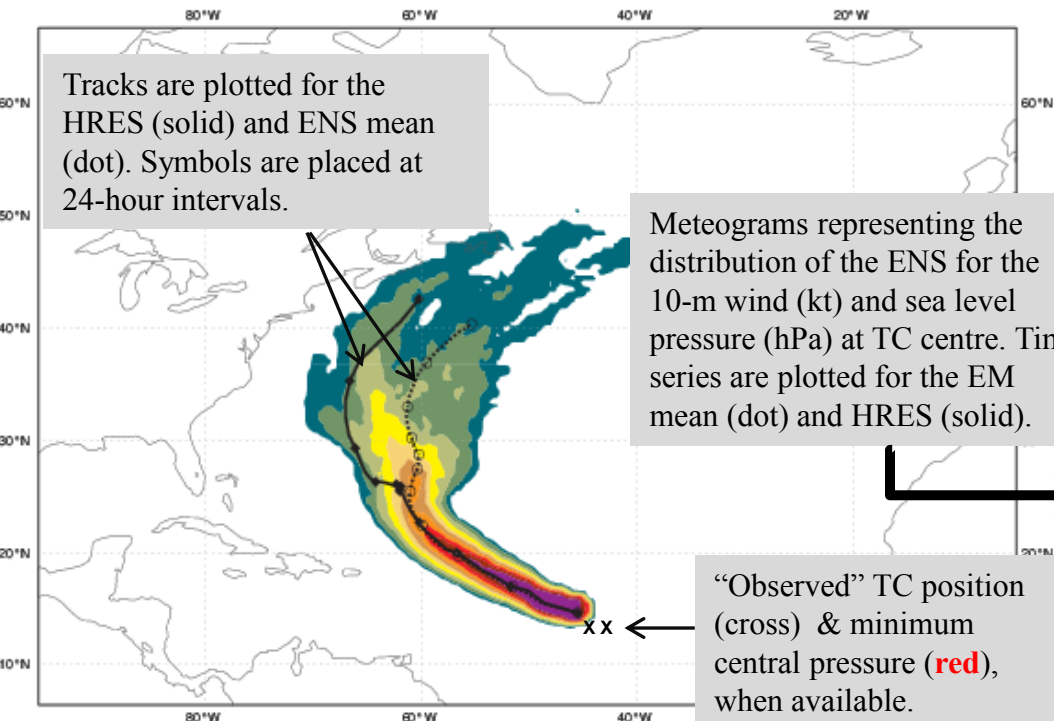
Date 20120831 00 UTC @ECMWF  
 Probability that **LESLIE** will pass within 120 km radius during the next 240 hours  
 tracks: **solid**=OPER; **dot**=Ens Mean [reported minimum central pressure (hPa) **1002** ]



Tracks are plotted for the HRES (solid) and ENS mean (dot). Symbols are placed at 24-hour intervals.

Meteograms representing the distribution of the ENS for the 10-m wind (kt) and sea level pressure (hPa) at TC centre. Time series are plotted for the EM mean (dot) and HRES (solid).

“Observed” TC position (cross) & minimum central pressure (red), when available.



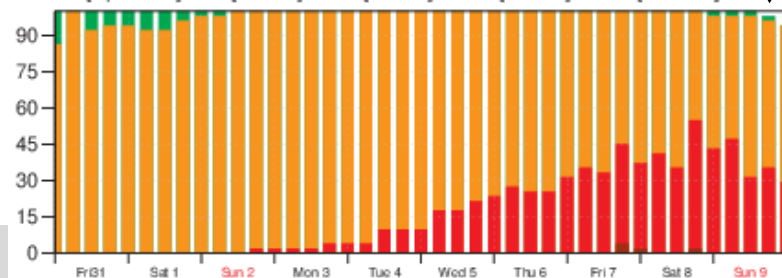
List of ensemble members numbers forecast Tropical Cyclone Intensity category in colours: **TD**[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[ >95 kt]

+024 h	:hr	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
+048 h	:hr	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
+072 h	:hr	ct	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
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+240 h	:hr	ct	01	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	40	41	42	43	44	45	46	47	48	49	50		

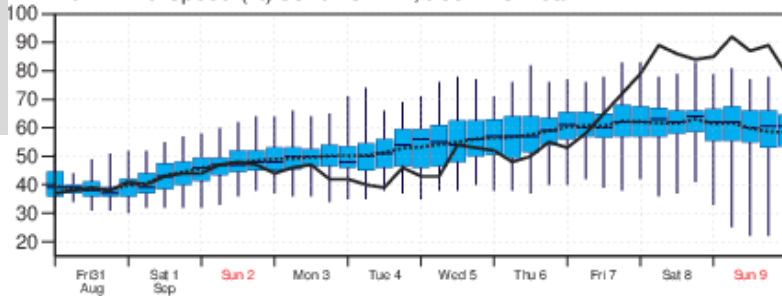
Snapshot of ENS members (numbers) tracking the storm together with intensity (colours), at 24-hours intervals. HRES and Control models are labelled ‘hr’ and ‘ct’ respectively.

Intensity probability is the fraction of the number of ENS members (relative to the total number of ENS members which held the feature) falling into each of the 5 intensity categories, at 6-hours interval up to 10 days.

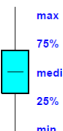
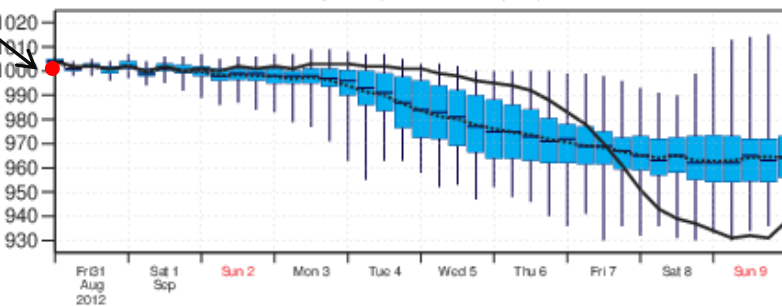
Probability (%) of Tropical Cyclone Intensity falling in each category  
**TD**[up to 33] **TS** [34-63] **HR1**[64-82] **HR2** [83-95] **HR3** [> 95 kt]



10m Wind Speed (kt) **solid**=OPER; **dot**=Ens Mean



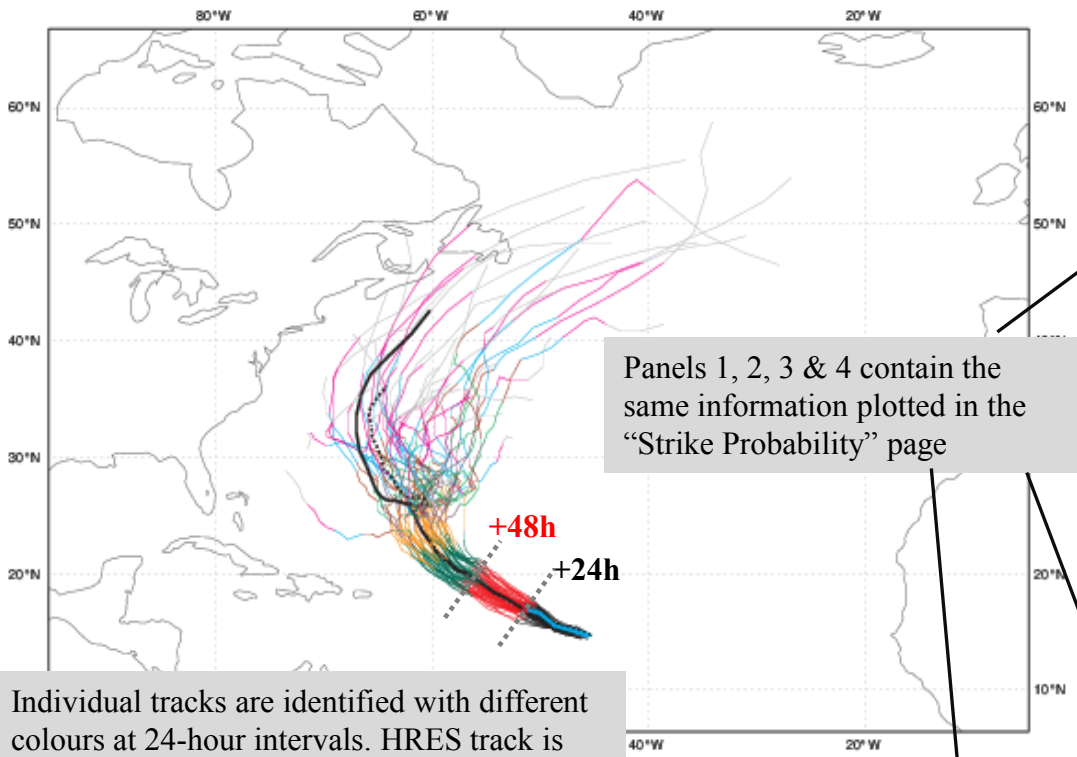
Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) **solid**=OPER; **dot**=Ens Mean



box-and-whiskers plot representing the 5 quantiles of the ENS distribution

# TC Products – Part II

Date 20120831 00 UTC @ECMWF  
 Individual trajectories for **LESLIE** during the next 240 hours  
 tracks: **thick solid**=OPER; **thick dot**=CTRL; **thin solid**=EPS members [coloured]  
**0-24h 24-48h 48-72h 72-96h 96-120h 120-144h 144-168h 168-192h 192-216h 216-240h**



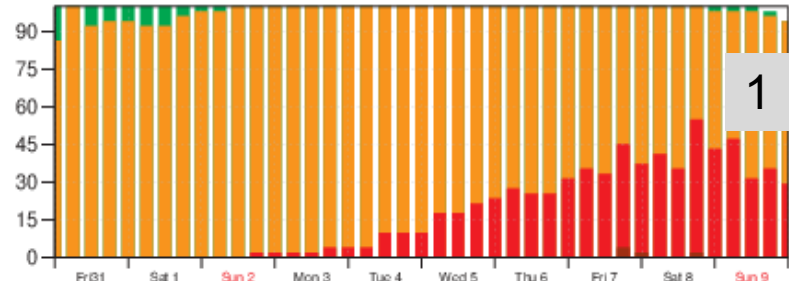
Panels 1, 2, 3 & 4 contain the same information plotted in the "Strike Probability" page

Individual tracks are identified with different colours at 24-hour intervals. HRES track is plotted with thick black line, except in the first 24-hours forecast (cyan).

Time	0-24h	24-48h	48-72h	72-96h	96-120h	120-144h	144-168h	168-192h	192-216h	216-240h	
+048 h	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	hr ct 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

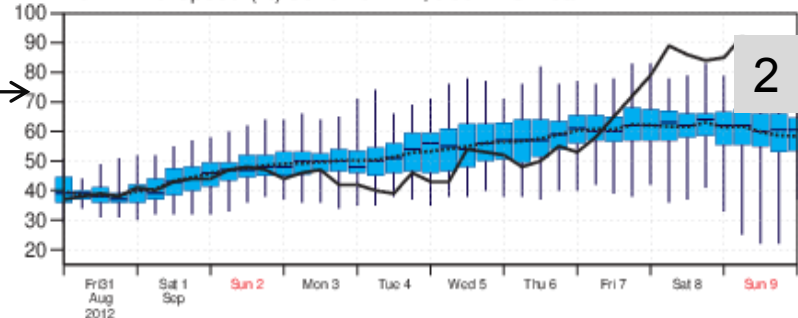
4

Probability (%) of Tropical Cyclone Intensity falling in each category  
**TD**[up to 33] **TS** [34-63] **HR1**[64-82] **HR2** [83-95] **HR3** [> 95 kt]



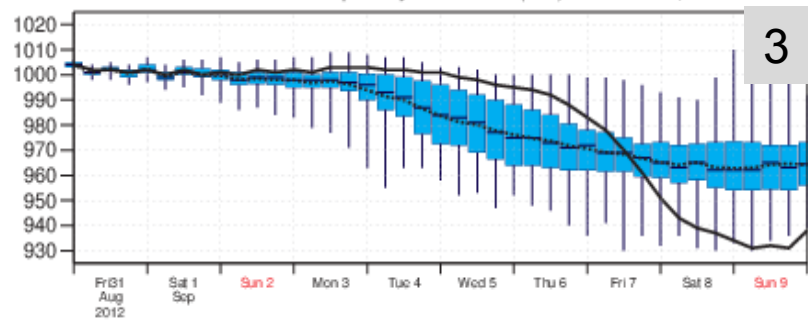
1

10m Wind Speed (kt) **solid**=OPER; **dot**=Ens Mean



2

Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) **solid**=OPER; **dot**=Ens Mean

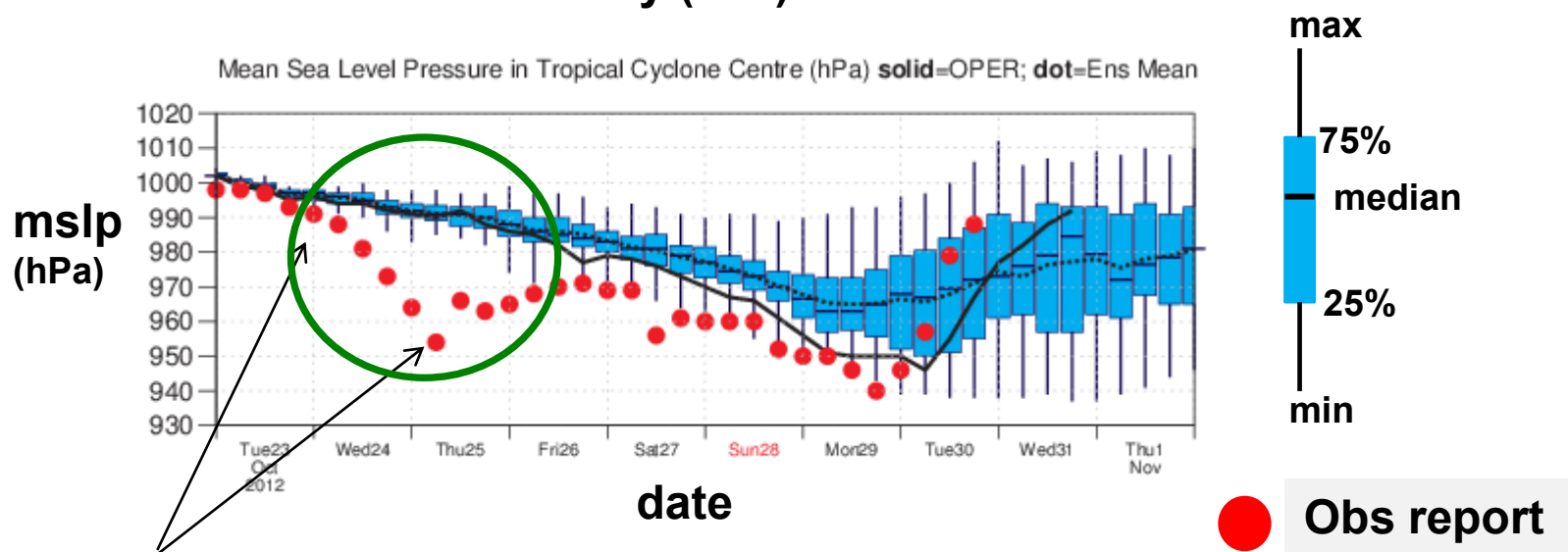


3

# TC intensity forecast – on going problem

- In general , rapid intensification of TCs is still poorly handled by the current global models

## HR Sandy (18L)



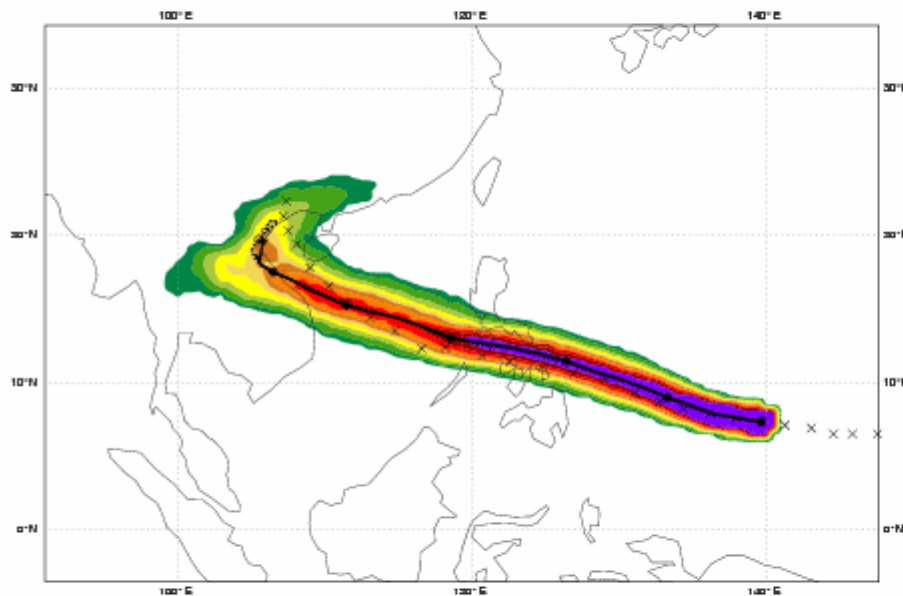
Rapid intensification  
~40 hPa in 30 hrs

# Haiyan 2 days before landfall

Date 20131106 00 UTC @ECMWF

Probability that **HAIYAN** will pass within 120 km radius during the next 240 hours  
 tracks: **solid**-OPER; **dot**-Ens Mean [reported minimum central pressure (hPa) **955** ]

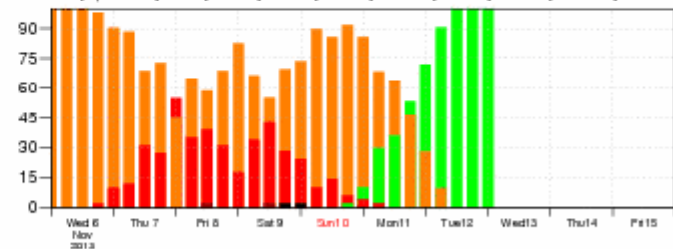
■ 0-10 ■ 10-20 ■ 20-30 ■ 30-40 ■ 40-50 ■ 50-60 ■ 60-70 ■ 70-80 ■ 80-90 ■ >90%



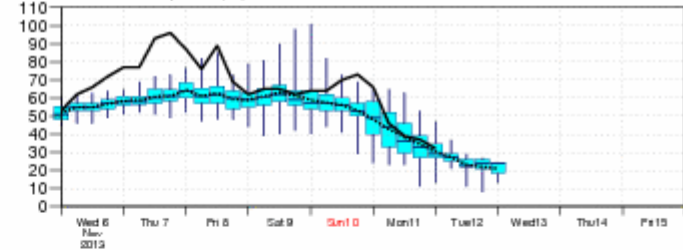
List of ensemble members numbers forecast Tropical Cyclone  
 Intensity category in colours: **TD**[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[>95 kt]

+024 h:	hr	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
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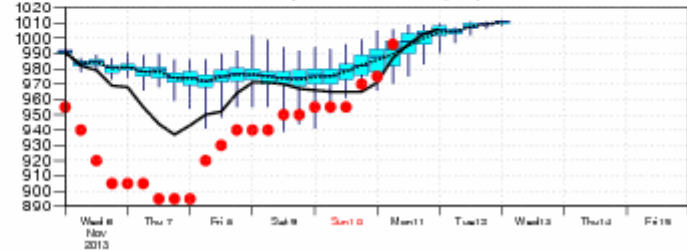
Probability (%) of Tropical Cyclone Intensity falling in each category  
**TD**[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[>95 kt]



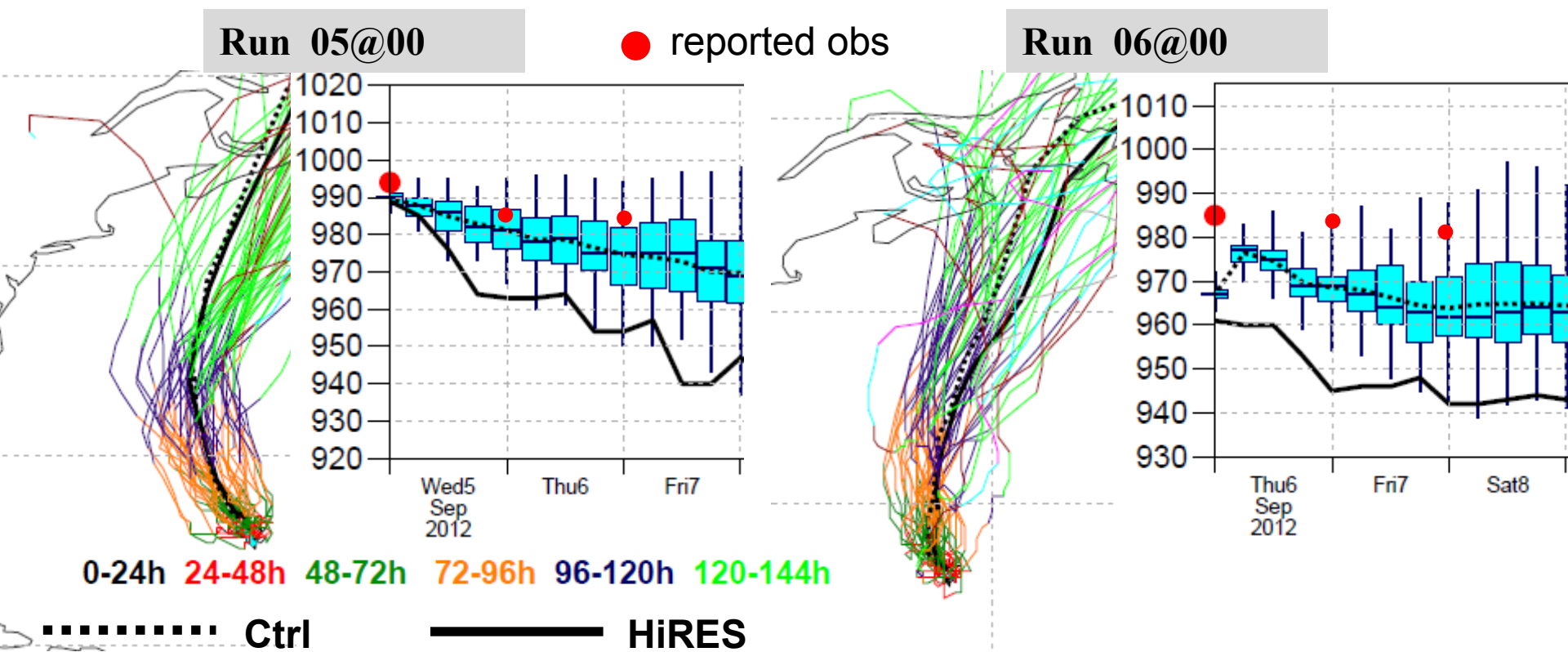
10m Wind Speed (kt) **solid**=OPER; **dot**=Ens Mean



Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) **solid**=OPER; **dot**=Ens Mean



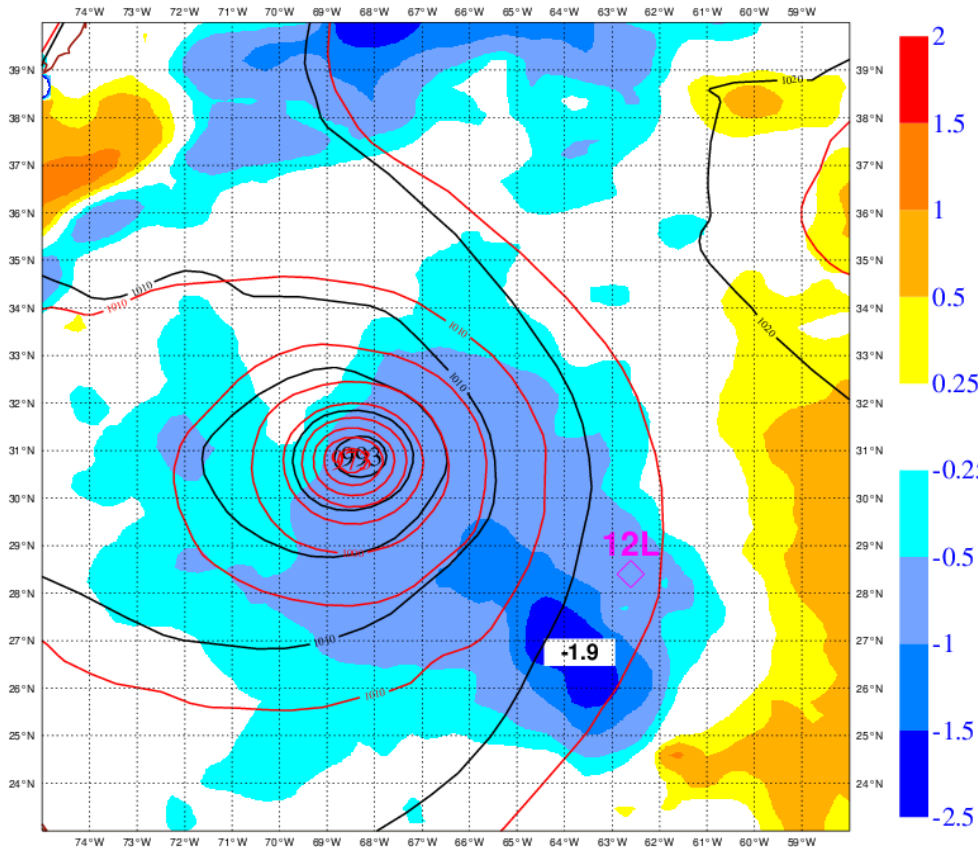
# Too intense TC (12L Leslie) analysis and forecast due to non couple ocean-atmosphere model



Each line represents an individual TC track ENS member (colours change every 24h interval)  
The individual tracks suggest a very slow moving storm during the first days  
The HiRes analysis shows a too deep storm between 6 and 8<sup>th</sup> September



# Coupled ocean and atmosphere (cont...)



**Control: operational T639  
(constant SST anomaly)**

**Experiment: coupled ocean-  
atmosphere model**

**contours: MSLP (hPa)**

**shaded: SST (K) difference (Exper-**Ctrl**)**

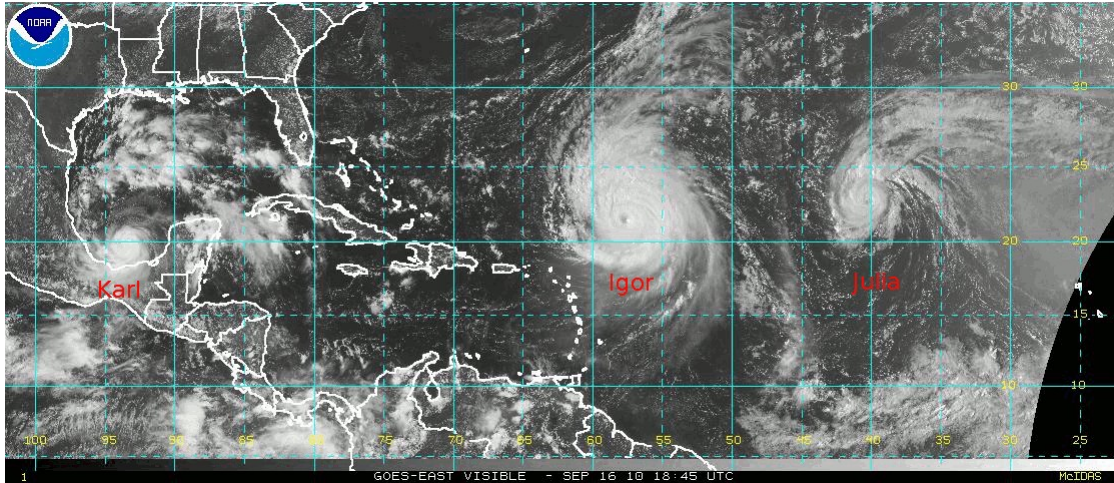
**Minimum Central Pressure:**

**993 hPa (Experiment)**

**973 hPa (Control)**

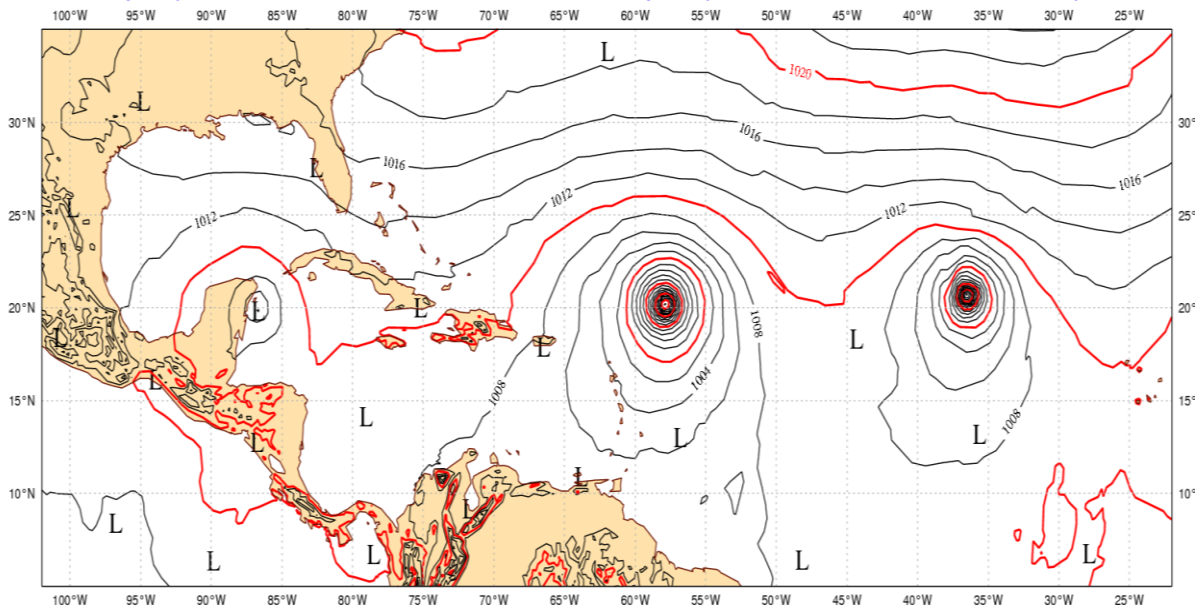
**03 Sep 12 UTC +120h VT: 08 Sep 12 UTC**

# Forecast period of enhanced Hurricane Activity, 9 days ahead



Goes-East visible image  
16 September 18 UTC

Wednesday 8 September 2010 00UTC ECMWF Forecast t+210 VT: Thursday 16 September 2010 18UTC Surface: Mean sea level pressure



T+210 h T1279  
Forecast MSLP

# Tropical Cyclone Activity Medium Range EPS

Selected forecast steps covering the next 12 days

Maps: global view and 7 additional TC basins



A short explanation about the products is available here by clicking in the show guide

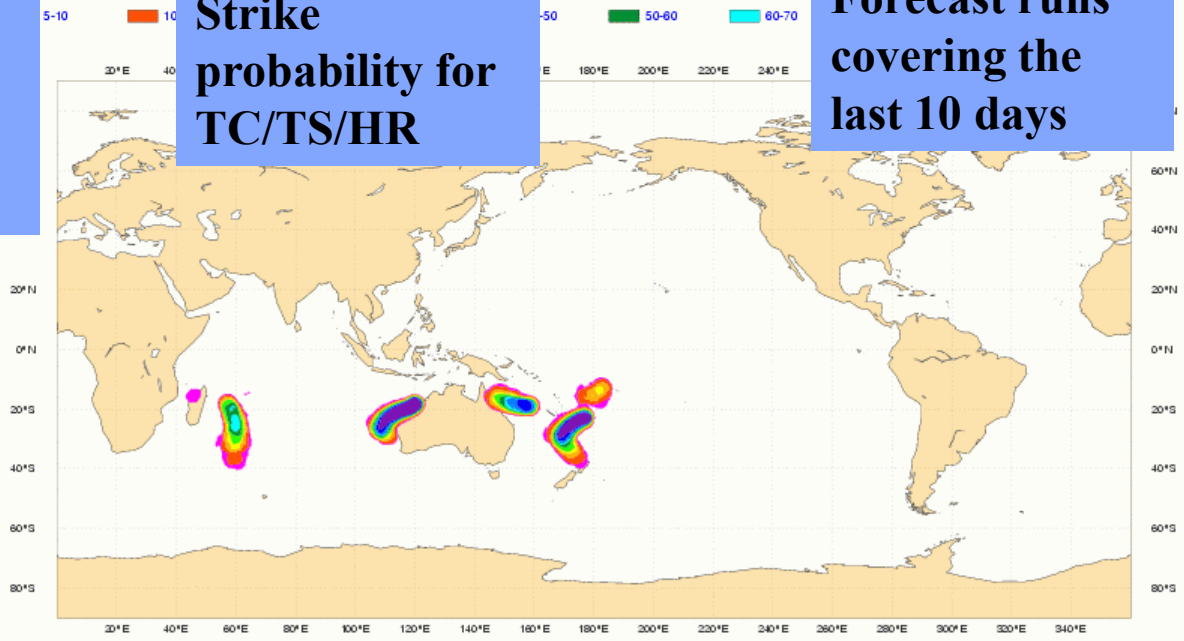
Tropical cyclone activity (including genesis)

Range: 24-72 Intensity: Tropical storms Area: Global Forecast base time: Tue 25 Jan 2011 12UTC

Tropical Storm Strike Probability Start date Tuesday 25 January 2011 at 12 UTC  
Valid for 48hours from Wednesday 26 January 2011 at 12 UTC to Friday 28 January 2011 at 12 UTC  
Probability of a Tropical Storm passing within 300km radius

Strike probability for TC/TS/HR

Forecast runs covering the last 10 days



# Forecast performance

The forecast performance for TCs is checked regularly and compared with the previous years for the Global HRES model and ENS. The results are reported to the Technical Advisory Committee<sup>★</sup> every year.

- Mean position error for HRES, Control models and ENS mean
- Mean intensity error (ME)
- Mean speed error (ME) for HRES
- Reliability and ROC for the Strike Probability Products
- ENS Spread & EM Error

★ also available in technical memoranda document

<http://www.ecmwf.int/publications/library/do/references/list/14>

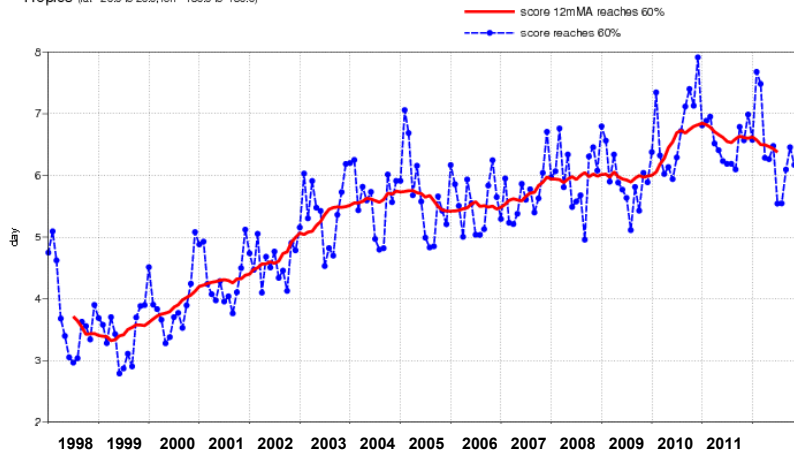
# How accurate are the TC forecasts from ECMWF (Part I)?

## ECMWF deterministic 00,12UTC forecast skill

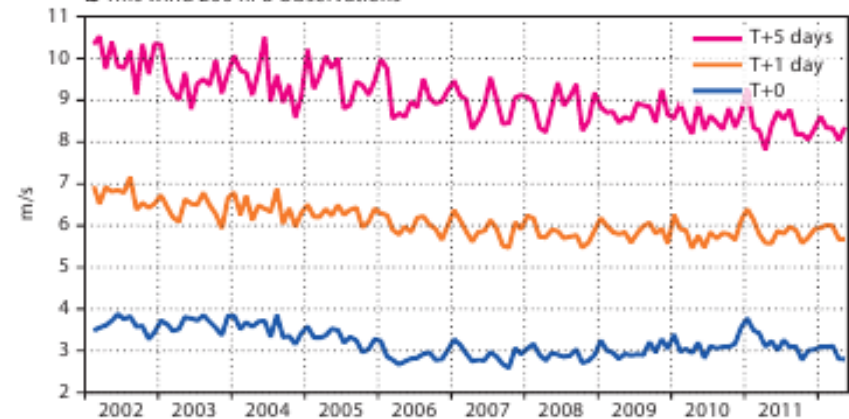
850hPa vector wind

Lead time of Anomaly correlation reaching 60%

Tropics (lat -20.0 to 20.0, lon -180.0 to 180.0)



## b rms wind 200 hPa Observations



**Lead Time of ACC 60% winds 850 hPa**

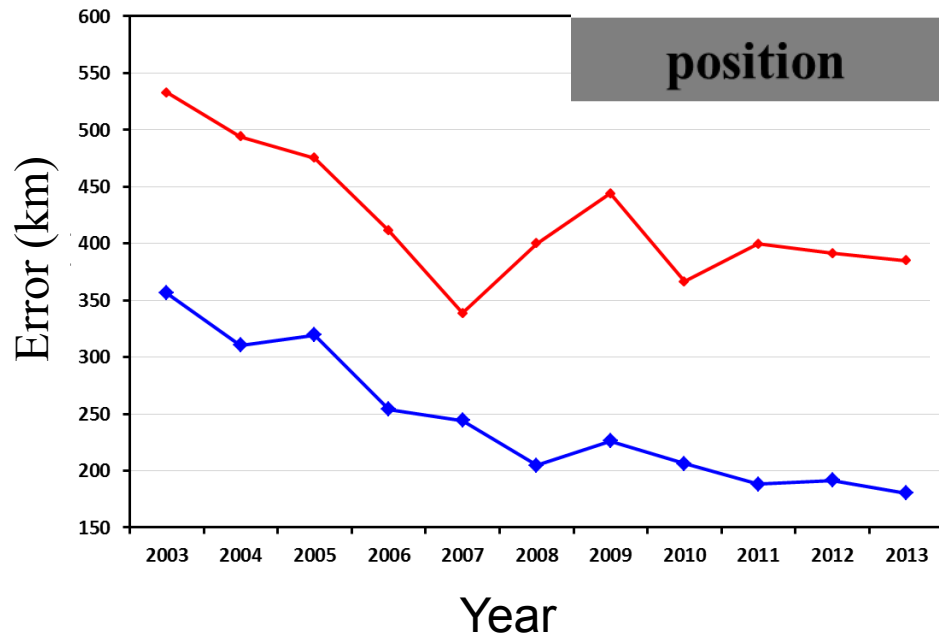
**RMS winds 200 hPa (against observations)**

A performance gain of ~2.5 days since early 2000 for winds at 850 hPa

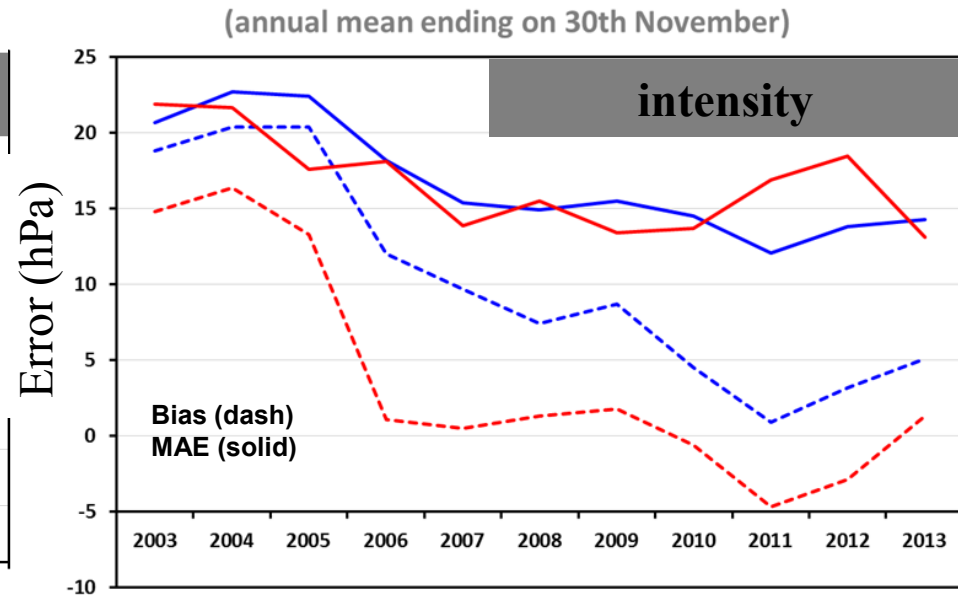
# How accurate are the TC Fcs from ECMWF (Part II) ?

HRES verification (12 month means ending on 30 November)

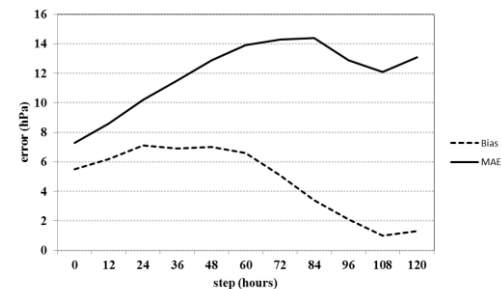
Mean position error D+5 & D+3 HRES  
(annual mean ending on 30th November)



bias and mean absolute intensity errors D+5 and D+3  
HRES

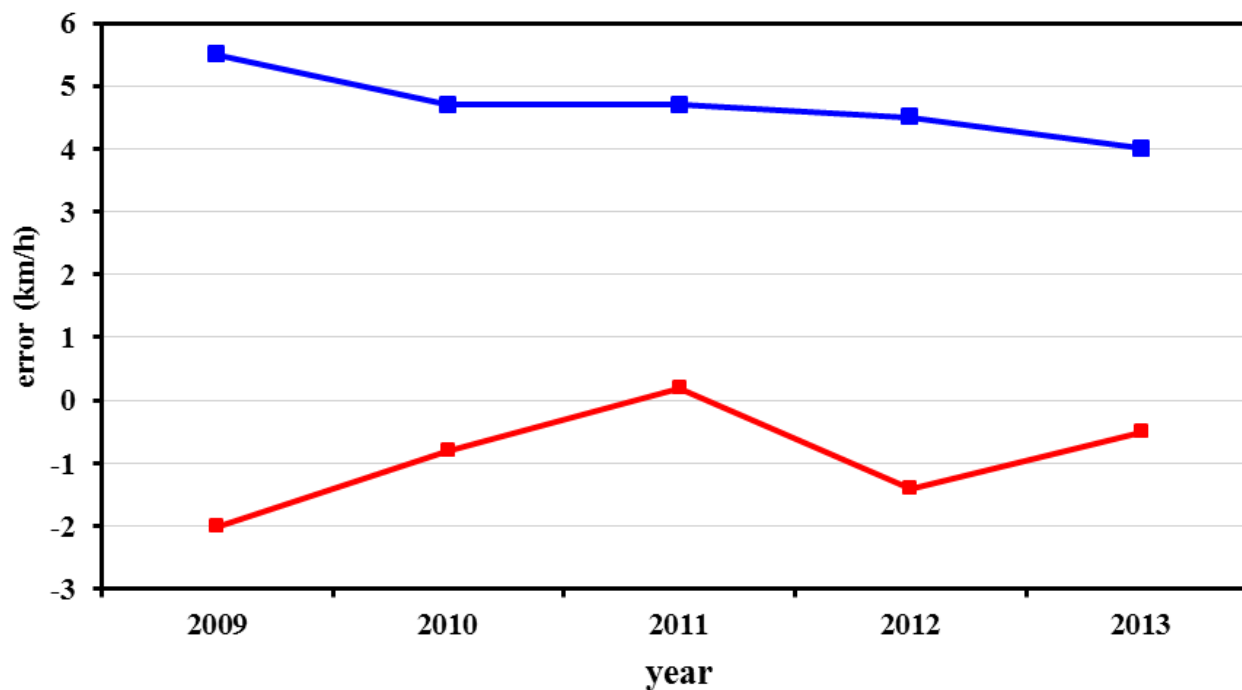


$Error = Forecast - Obs$   
Obs from the best track reports



# On average TCs move slower in the model (Part III)

Mean absolute speed error (blue) D+3 &  
mean speed error (red) HRES model  
(annual mean ending on 30th November)



# How do we performed against the other NWP Centres (Part IV)?

source: Hong Kong observatory

- 2011 verification results
- ECMWF is clearly best model
- ECMWF is comparable to or better than the multi-centre ensemble mean (“NWP ensemble”)

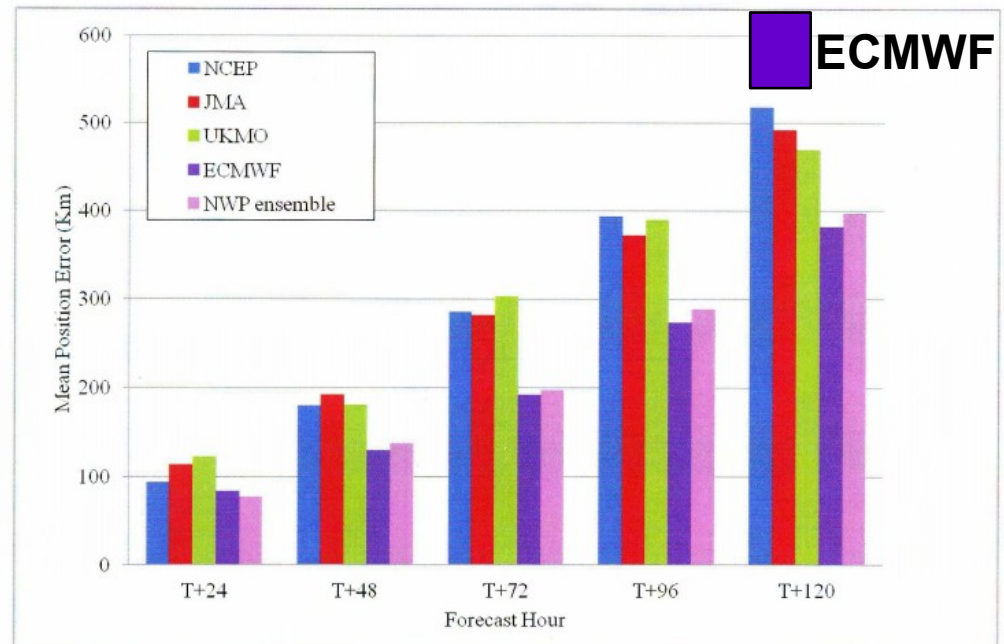


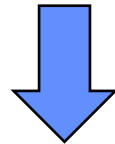
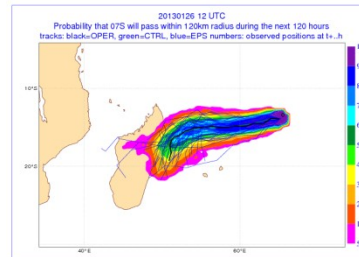
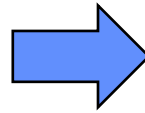
Figure 7. Mean position errors of forecasts from the NWP ensemble and the respective member models for T+24 to T+120 in 2011.

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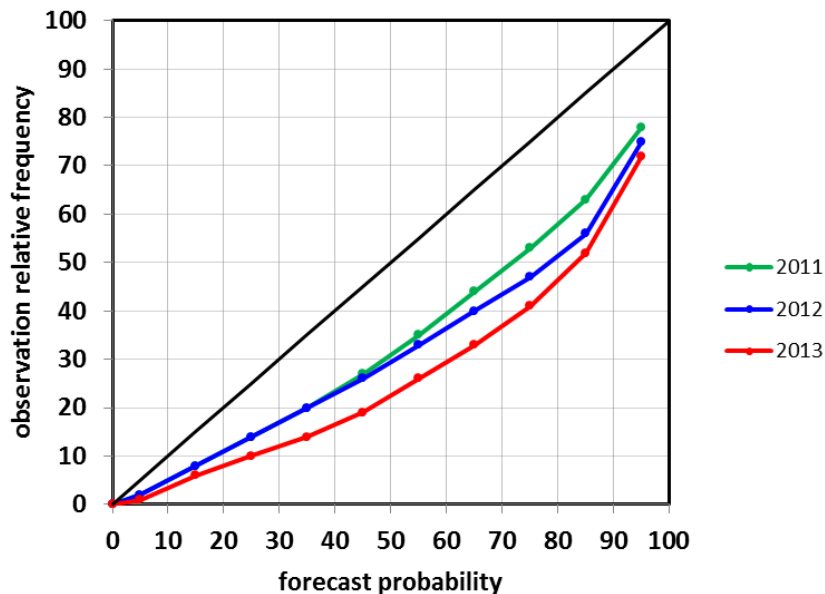


# Verification of the ENS Strike Probability product (Part V)

Strike probability of TC within 120 km in the next five days

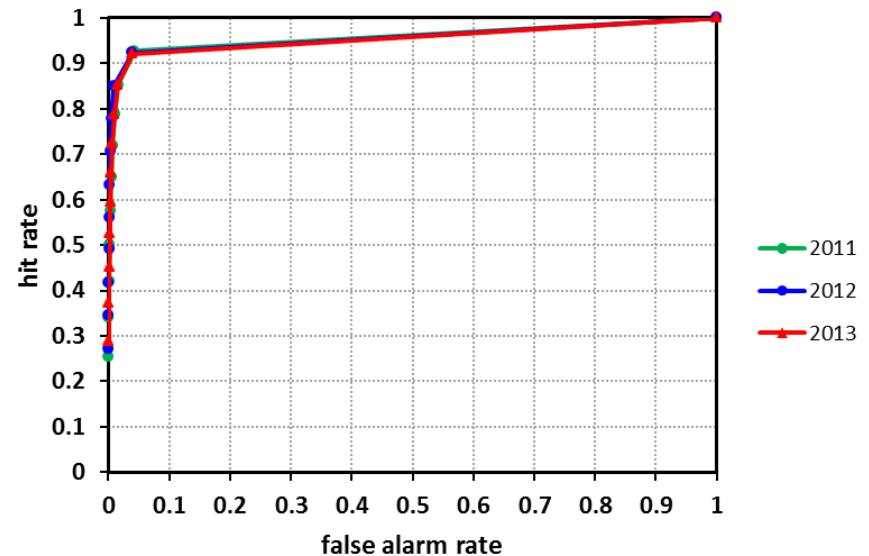


### Reliability of TC strike probability (one year ending on 30th Nov)



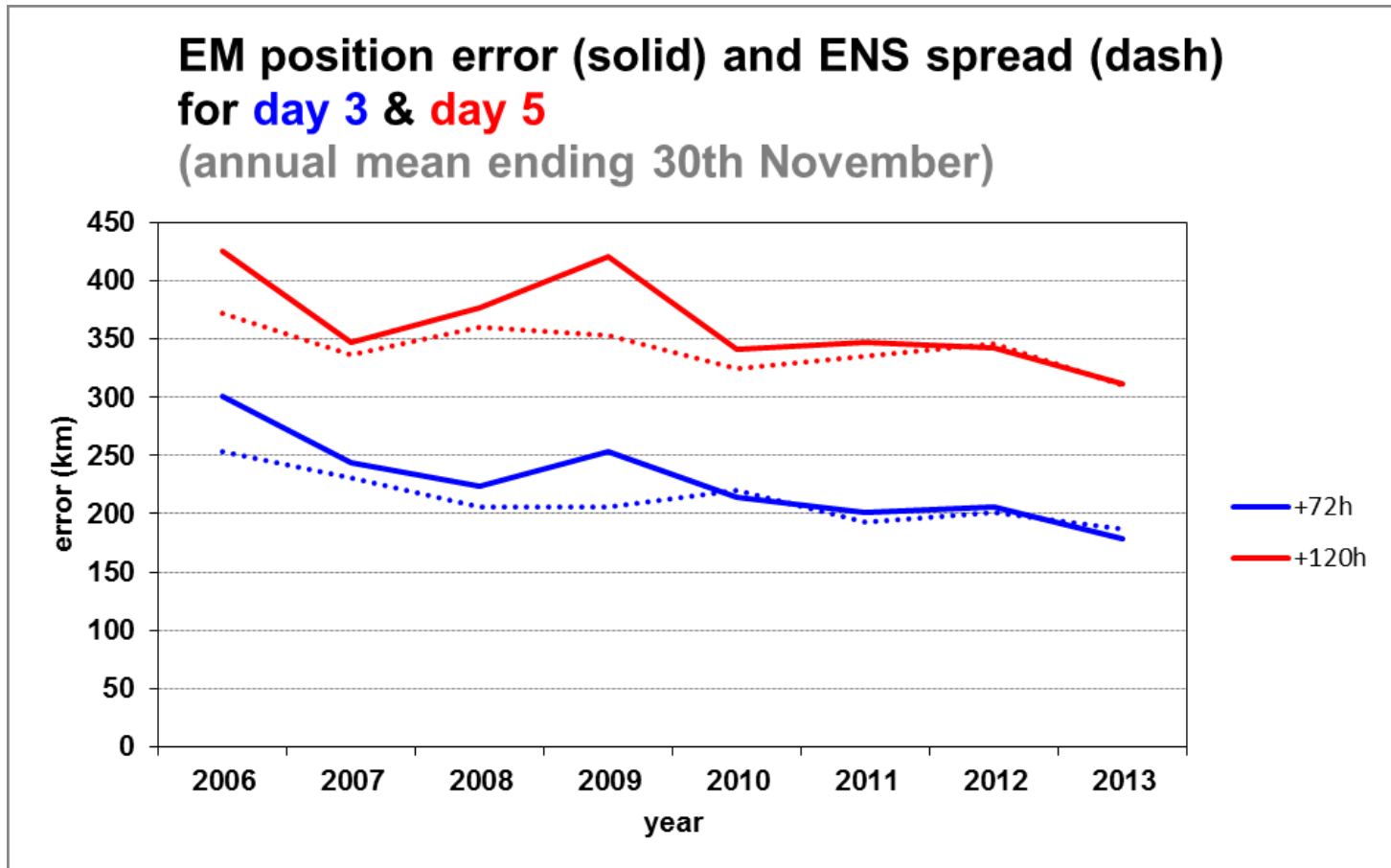
### ROC of TC strike probability (one year ending on 30th Nov)

ROCA: 0.923/0.921/0.923



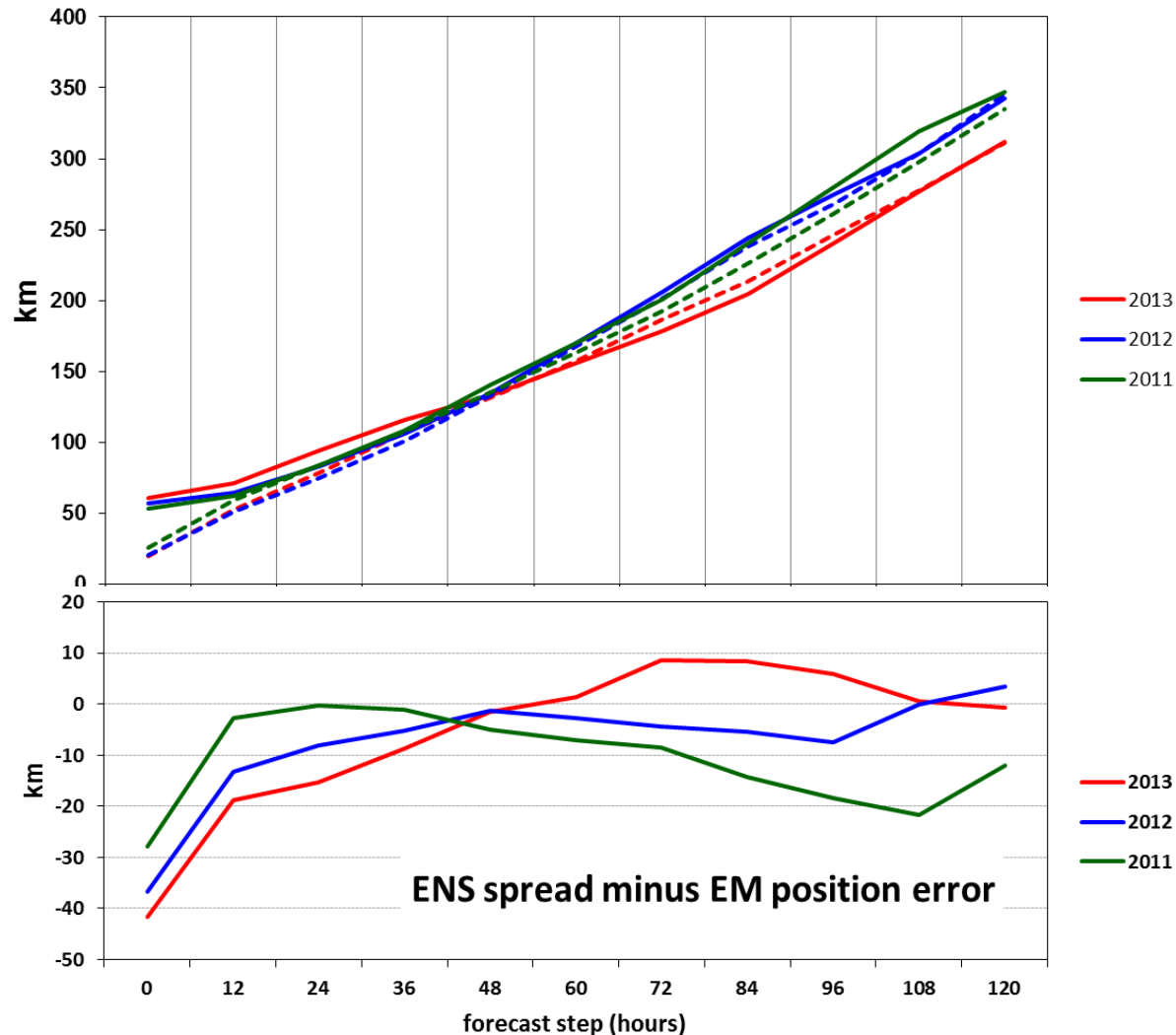
# ENS SPREAD & EM ERROR (Part VI)

A calibrated ENS should provide consistency between the EM error and spread.



# ENS SPREAD & EM ERROR (Part VII)

EM position error (solid) and ENS spread (dash)  
(annual mean ending 30th November)



# QUESTIONS?